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# Research on coal mine gas sensor systems based on near infrared spectrum

Haiqing Zhang , Mengran Zhou, Can Song, Di Wu

Department of Electrics and Information Engineering,Anhui University of Science and Technology, Huainan,232001,China

**Abstract**

Explosion caused by gas is one of the major coal mine accident, and real-time detection of the coal mine gas is becoming more and more important. In this paper we introduce a method based on near infrared spectrum coal mine gas sensor systems aiming at the errors caused by background-interference in detection on the concentration of methane gas in the past. We choose equal-absorption method in the experiment to eliminate the inaccuracy caused by spectrum of other gas absorbed at the same time. Also, we make use of a absorption cell to eliminate inaccuracy caused by different absorption parameters and interference caused by background. The experiment shows that the effect is very good. 

错误！未找到引用源。near infrared spectrum; sensor ; equal-absorption point method ;gas; two—wavelength

## 1. Introduction

With the development of the industry and increasing of the coal mine consumption, the mining scale and depth is improving these days. More and more escaping gas from coal mines security risks also increases. The proportion of Grave and serious accident is getting higher and higher[1,2,3].

Laser-optical sensors are now at the threshold of routine applications in air pollution monitoring and industrial process and gas analysis. The development of this technology has been driven mainly by scientific questions, but increasingly these sensors are transferred to industrial and other applications whenever sensitive, selective and fast analysis is required. With the increasing complexity of processes, online gas analysis is becoming a key issue in automated control of various industrial applications[4,5]. we will describe a near-infrared trace-gas sensor for methane.

We use a method based on two-wavelength equal-absorption point in near infrared spectrum to detect the gas concentration, where two-wavelength refers to two monochromatic light beams from the same light source. Thus, there isn't much influence from light source, which is a vital advantage in sensitivity and selection compared with other optical near infrared spectrum detection technology. At the same time, taking the advantage of optical fiber also makes the spectrum analysis technology develop rapidly in detection sensitivity and remote monitoring.

* Zhang haiqing Tel.:13635548317.
E-mail address: yyu0825@163.com.

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## 2. Principle of the near infrared spectrum

Optical fiber near infrared spectrum gas sensor systems generally find out the wavelength of the appropriate gas, precalculate the optical-absorption coefficients and then solve the equation . There are other methods based on the same principle can also find out the the optical-absorption coefficient , but really full of inconvenience and inaccuracy, especially when mixed- category absorption spectrums are similar, so that we frequently can't get satisfying result[6]. In this paper we choose the method based on two-wavelength equal-absorption point in near infrared spectrum to detect the gas concentration, and select a structure of two-wavelength $\lambda_1$ and $\lambda_2$ reasonably to avoid calculation. And that is convenient and accurate.

### 2.1. Principle of the two-wavelength equal-absorption point method

It selects two wavelengths from the absorption curve to make sure the difference between the absorption level of the group to be detected is large enough and the interfering group is 0,thus eliminating the interference of the interfering group[7,8]. Here is the equation derivation:

Set contains the group was divided into a, b of the analytes , $\lambda_1$ and $\lambda_2$ at the wavelength of light absorption coefficients were

$$A_{\lambda 1} = \varepsilon_a c_a + \varepsilon_b c_b \quad (1)$$

$$A_{\lambda 2} = \varepsilon'_a c_a + \varepsilon'_b c_b \quad (2)$$

Where $\varepsilon_a$ , $\varepsilon_b$ are the molar absorption coefficients when wavelength is $\lambda_1$ , so the $\varepsilon'_a$ and $\varepsilon'_b$ when wavelength is $\lambda_2$ ,and $c_a$ and $c_b$ are the mol concentration of a and b.

Subtracting the two equations obtained in two wavelength difference between the absorbance coefficient $\Delta A$ .

$$\Delta A = A_{\lambda 1} - A_{\lambda 2} = (\varepsilon_a - \varepsilon'_a)c_a + (\varepsilon_b - \varepsilon'_b)c_b \quad (3)$$

If the two selected wavelengths, the component b, the molar absorption coefficients are equal, then

$$\Delta A = (\varepsilon_a - \varepsilon'_a)c_a \quad (4)$$

Thus $\Delta A$ we detected does not depend on the concentration of b, the elimination of the interference from group b.

On the contrary, we have

$$\Delta A = (\varepsilon_b - \varepsilon'_b)c_b \quad (5)$$

### 2.2. Principles of two-wavelength measurement

Two-wavelength detection method is developed upon traditional basis, the theoretical basis is the differentiate technology and equal absorption wavelength. The difference of tradition method is that it uses two different wavelengths (measure wavelength and reference wavelength) to determinate a sample on the same time, to overcome the shortages of a single wavelength determination and improve the determination results precisely and accurately[9].

Light source basically uses broadband light source，it selected by two monochromators of different wavelengths, the measurement wavelength is $\lambda_1$ , the reference wavelength is $\lambda_2$ , after the two wavelengths light going through the gas chamber the output are:

$$I(\lambda_1) = I_0(\lambda_1)K(\lambda_1)\exp((-a_{\lambda 1}cl)) \quad (6)$$

$$I(\lambda_2) = I_0(\lambda_2)K(\lambda_2)\exp((-a_{\lambda 2}cl)) \quad (7)$$

In the formula, $I(\lambda_1), I(\lambda_2)$ respectively means the output light intensity when light detector selects the wavelength of $\lambda_1, \lambda_2$ ; $I_0$ means luminous intensity of light source; $K(\lambda_1)$ , $K(\lambda_2)$ respectively means photoelectric sensitivity of light detector at $\lambda_1, \lambda_2$ .After adjusting the optical path makes $K(\lambda_2)I_0(\lambda_2) = K(\lambda_1)I_0(\lambda_1)$ ,according to formula (6)/(7) we can get:

$$\frac{I(\lambda_1)}{I(\lambda_2)} = \exp(-a_{\lambda_1}cl + a_{\lambda_2}cl)$$

$$c = \frac{1}{(a_{\lambda_2} - a_{\lambda_1})l} In \frac{I(\lambda_1)}{I(\lambda_2)} \quad (8)$$

## 3. Experiment

As the spectrum absorption coefficients space of water is similar to that of methane gas, the interference from the water should be eliminated. Measurement wavelength is selected as 1.6654 $\mu$ m from calculating by equal-absorption method when and reference wavelength is 1.590 $\mu$ m when selecting two-wavelength, as the water absorption coefficients are similar at these two wavelengths. 1.6654 $\mu$ m is selected in experiment[10,11].

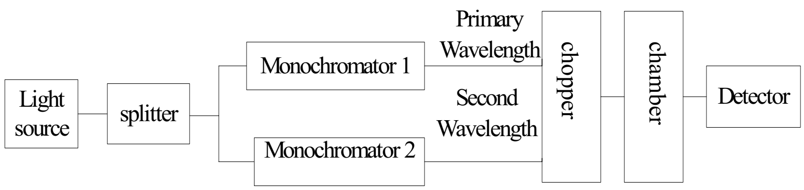


Figure 1: Block diagram of fiber optical methane sensing system based on near infrared spectrum.

The corresponding band of laser is split into two beams by splitter. Because wavelength is fix, so using optical filters obtain monochromatic light in order to simplify the equipment installation and save cost.The laser beam is then transmitted to the gas cell by fibre optics, launched across the gas cell and returned to the detector by fibre optics. The probe consists of a perforated tube terminating with a retroflector at one end, a set of two off axis parabolic mirrors (OAP) at the other end. The OAPs are used to collimate the laser light from the incoming fiber and to refocus the returned light on the outgoing fiber. Both signals are then digitized and further processed by digital filters, line locking, normalization and calibration procedures.

The length of methane gas absorption cell is selected as L=50cm at room temperature. The receiving-end receives pulse signals with different phases in the same light beam and two different wavelengths. Phase corresponding is converted into pulse electric signal. Because of the same light beam, errors from different light beams are eliminated, thus sensitive and accuracy are improved.

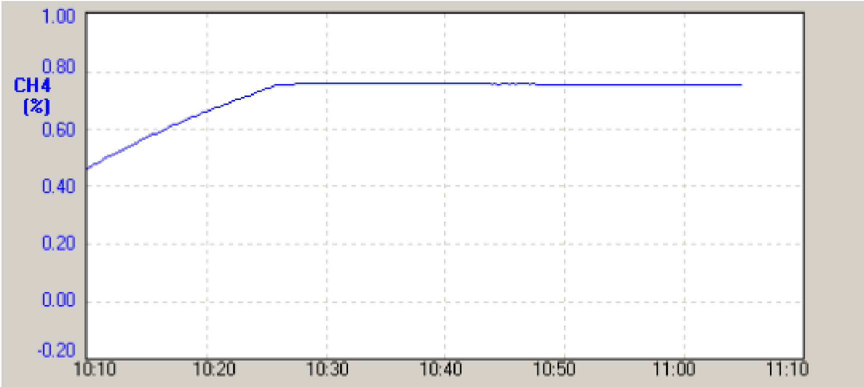


Figure2 A real-time record of trend analysis

Also we have a stability test for the system. First of all, standardize the system and adjust the zero points and cap of the system. We inject concentration of 1.17% standard methane gas into the air cell, waiting for it stabilizing and recording the indicating value. Repeat this process every 10 hours when the test is proceeding continuously. Indicating value is shown as diagram 1.

Table 1 Experiment data of stability

| time | measured value（%） | time | measured value（%） |
|---|---|---|---|
| 1 | 1.18 | 7 | 1.27 |
| 2 | 1.21 | 8 | 1.19 |
| 3 | 1.22 | 9 | 1.21 |
| 4 | 1.24 | 10 | 1.20 |
| 5 | 1.23 | 11 | 1.22 |
| 6 | 1.19 | 12 | 1.20 |

Indication in the record to take the maximum drift value, the stability according to formula

$$\delta = \frac{C_2 - C_1}{R} \times 100\% = \frac{1.27 - 1.18}{6} \times 100\% = 1.5\%$$

After standardizing, try comparing experiments using different concentrations of methane gas. Concentrations of the label gas should be within space 0~1% in experiment as the detection system will alarm if the concentration is over 1%.From detection value and label value we can see the relative error. The relative error can be calculated from diagram 2.

Table 2 Experiment data of calibration

| Serial number | Input values (%) | Output values (%) | Relative error (%) |
|---|---|---|---|
| 1 | 0.000 | 0.000 | 0.00 |
| 2 | 0.200 | 0.198 | -1.00 |
| 3 | 0.400 | 0.397 | -1.50 |
| 4 | 0.600 | 0.601 | 0.50 |
| 5 | 0.800 | 0.803 | 0.15 |
| 6 | 1.000 | 1.004 | 2.00 |

## 4. Conclusions

Using two-wavelength absorption spectroscopy technique designs a two-wavelength single optical fiber methane sensor based on equal-absorption point method, in the experiments light of the same source will be split into two beams, so that two-wavelength monochromatic light intensity is relatively stable, Experiment to measure the wavelength and reference wavelength of the two beams through the same absorption cell in order to eliminate the absorption cell parameters caused by different error. And the systems will fill an important niche in the market where specific gases need to be monitored with high specificity and moderate sensitivity. The ease of operation should make it an attractive method for industrial and regulatory markets.

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